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HYDROGEOLOGIC EVALUATION
OF THE
PONCE CENTER FOR ENVIRONMENTAL CONTROL SITE
PONCE, PUERTO RICO

PRD980594709

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1.0 GENERAL ASSESSMENT

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An extensive effort has been made by the applicant and the company's consultants to assess ground-water conditions at the Ponce Center for Environmental Control site. The effort included the installation of monitoring wells and piezometers; the performance of soil borings and testing, down-hole gamma logging, seismic refraction surveys, permeability testing, water level monitoring; and, chemical and isotope analyses of water samples.

Ground-water evaluation at the site proceeded in two phases. Phase I comprised drilling of piezometers and monitoring wells coded MW-1 through MW-5, as presented in Appendix 7 of the latest RCRA Part B submission (6 June 1984). Additional wells MW-6, MW-7 and MW-8 were drilled during Phase II; this phase included isotope analyses to determine the origin and the residence time of ground water. The results of Phase II investigations are presented in Appendix 8 of the latest submission.

The Phase II results have revealed a much more complex site hydrology than indicated by the Phase I results. A re-interpretation of the ground-water flow direction based upon the Phase I potentiometric data (March 1984) reveals a flow direction opposite to an earlier (April 1983) concept. However, it was not possible to deduce potentiometric surface contours with the most recent data.

A number of hypotheses and ground-water flow "scenarios" are discussed by CECOS' consultants, Law Engineering Testing Company, in Appendix 8. These hypotheses indicate that the site hydrogeology is quite complex and requires further investigation. A concept of nearly stagnant ground water, entrapped within tectonic blocks isolated by faults, has been proposed to explain the disjointed character of water levels at the site. The concept is supported by the ground water radiocarbon dating results and other exploration data.

Indeed, tectonics in general, and faulting in particular, appears to be a major factor controlling ground-water occurrence at the site. It is not possible, however, to determine the number of tectonic blocks, nor to accurately determine the block boundaries, with the current exploration data.

It appears that nearly all of the 13 boreholes that reached ground water at the site were located in a separate fault-block (see attached reviewer's cross-sections).

Isotope analyses of water samples from six monitoring wells have provided some valuable information on the origin and mean residence time of ground water. The water is undoubtedly of meteoric origin, not connate as originally hypothesized, and the mean residence times are on the order of thousands of years. The disturbing fact is, however, that the residence time (Age 1) varies greatly from a fairly "recent" time (MW-2) to 1700 years for MW-6, which displays the deepest water level at the site, and up to 10,200 years for a shallow well, MW-4. The carbon isotope results, while supporting the concept of a slow flushing, fault-controlled ground-water system at the site, indicate that some privileged pathways for a relatively faster ground-water movement may exist at the site.

The proposed ground-water monitoring program for Cells #1, 2, and 3 consists of 11 wells which are so located to encompass the waste management area. A horizontal projection of the proposed "compliance point" roughly coincides with the waste management area boundary. It is argued by the applicant that the concept of upgradient and downgradient wells, implicit in the definition of the point of compliance, is not appropriate for the site where a "no-flow" ground-water system exists.

In fact, the proposed point of compliance, encircling the waste management area, stems from the inability to adequately define the complex ground-water system at the site with currently available exploratory data, particularly in terms of the uppermost aquifer underlying the regulated units.

With this limitation in mind, the applicant offers a reasonable approach to ground-water monitoring at the site. Nevertheless, there are serious technical and regulatory concerns about the effectiveness of the proposed monitoring program.

The proposed monitoring system is based on the premise that any leachate leaking from a cell would move outward in all directions from the point of leakage until the leachate encounters the first continuously saturated ground-water zone beneath the cell. The contaminant plume would then move radially outward and, by diffusion, would reach any ground-water monitoring well screened in the contaminated zone (p. E-51).

According to the applicant, molecular diffusion would be the dominant contaminant transport mechanism within a fault block. Hypothetically, a plume originating in a cell center, and spreading by diffusion, would reach monitoring wells after more than 1,000 years (Figure E-16).

In addition to the diffusion model, a model of hypothetical plume spreading by ground-water movement has also been analyzed to assess the adequacy of proposed monitoring wells location. Realistic values of hydraulic and dispersivity parameters were used in the model, and the results (Figure E-15) suggest sufficient coverage of monitoring wells to detect a hypothetical contamination plume 5 to 10 years after a leakage occurred at the cell centers.

The underlying assumption for the validity of the latter model of contamination plume spreading is homogeneity and intergranular character of porosity and permeability of the aquifer. The presence of faults contradicts homogeneity. If permeability is fracture controlled or of mixed type (fracture plus intergranular), the prediction of potential contaminant migration directions and the adequacy of monitoring well locations become very complicated, particularly if site exploration data are still inconclusive.

This appears to be the case at the Ponce site. The following is an attempt to evaluate some basic aspects of the site hydrogeology.

2.0 SITE TECTONICS

Faulting is found to be a major factor controlling ground-water occurrence at the site. Understanding the faulting is thus a prerequisite for an assessment of site hydrogeology and the proposed monitoring system.

The site geologic map identifies a large, major fault under the fill and several smaller faults in the area of the cells. A concentration of faults within the northern bank of Cells #1 and #2 (roughly bounded by MW-7, MW-6, and C-1) should be noted.

It appears that the map gives a rather simplified picture of site faulting. The map should be updated to incorporate recent observations in cut slopes and boring data.

An apparently major fault was noted in the cut slope of a hill located at the northwest corner of the site, as reported in the geotechnical section of the latest submission (App. 3, p.5). The fault cuts the Ponce Formation and is marked by a 12 to 15-inch clay gouge and slickensides. An extensive brecciation of the Ponce Limestone is evident from geotechnical borings within the process facility area.

In the northern slope of projected Cell #2, just above the proposed tank area, the presence of three continuous and well-defined faults has caused movement of a large rock wedge (App. 3). The dip of the faults is within the 55° to 60° range, similar to the dip of the fault in the northwest site corner cut slope, and is typical for the dip of normal faults in calcareous materials.

Two of the faults north of Cell #2 belong to a system trending N40E. Neither they, nor the formerly mentioned fault, are indicated on the site geologic map.

Four major fault directions appear to be present within the waste management area. These are systems with fault traces:

1. Subparallel to the strike;
2. Subparallel to the dip of strata;
3. Subparallel to the major site fault; and
4. Oblique with a horizontal offset.

The most complicated tectonic situation exists in the northern areas of Cells #1 and #2, where a high fault frequency has resulted in tectonic blocks of a very small size (tens to hundreds of feet). A substantial offset of the blocks is associated with the oblique fault system. The complicated tectonics can be related to a change in the direction of the major site fault (see regional geologic map) occurring just south of the hill in the northwest site corner. More extensive faulting and offsets may have resulted from accommodation of stress concentration associated with the change in direction (splay) of the major fault.

Borehole data provide additional support of extensive faulting at the site. In a few cases, the presence of fragmented, brecciated rock (C-16 and MW-1, for example) or an apparent reversal of stratigraphic succession (green/orange/green "shale", as in MW-6) may be indicative of a fault passing through the borehole.

The reviewer has made an attempt to draw hydrogeologic sections (see attachments), more detailed than the sections presented in the application. Available borehole logs, gamma-logs, surface geology and ground-water data were used in preparation of the sections. The top of dark green Juana Diaz material was used as a stratigraphic marker, together with gamma-log peak intensity (an indication of higher clay content).

The sections are meant to illustrate the complexity of Ponce site hydrogeology and tectonics. Every borehole seems to define its own tectonic block. It is felt the proposed interpretation is still sketchy, open to debate, and subject to major changes when new exploration data becomes available. (The ability and ease to draw geologic/hydrogeologic sections is a simple criterion to determine if the current information is sufficient to characterize the site geologic and hydrogeologic conditions. The Ponce site is still underexplored if this criterion is used.)

There is substantial evidence that, in general, the faults may act as barriers to ground water flow. The evidence includes hydrogeologic data (water levels, age determinations), field observation of fault zones and results of tests on gouge material. However, one should be cautious to generalize the

"fault as barrier" concept to all the site faults and/or segments of a fault. It is likely that a hydraulic contact may exist along a portion of a fault surface which intersects another fault. As a rather impervious gouge material or a tight fault contact may quickly fade into a fractured or brecciated zone, an offset associated with the intersection of two faults belonging to different systems may create a hydraulic connection. It is very difficult (if possible at all with the exploration tools used on the site) to identify a possibly "leaking" portion of a fault, but the northern parts of Cells #1 and #2 appear to be more suspect areas for such a possible leak.

Two sets of steep (dip 55° to 75°), conjugate joints, orthogonal to the bedding, are reported at the tank area in the Juana Diaz Formation (Appendix 3, p. 3 of the second report). These joints are continuous and relatively tight. Joints subparallel to the borehole axis are sometimes reported in borehole logs. Note that the orientation of the vertical borehole is unfavorable to intersect and detect steep joint sets.

In addition to systematic jointing, there is evidence of fracturing and brecciation in some borehole logs, apparently related to faulting.

This review of site tectonics was necessary to evaluate some aspects of the proposed ground-water monitoring program. The proposed location of monitoring wells includes a criterion of placing at least one well in each block. This criterion is not met as:

- o The number of blocks (still unknown) appears to be much greater than the number of proposed monitoring wells;
- o Only one well (MW-3, in addition to existing Well MW-6) is proposed for the tectonically most complicated northern portion of Cell #1 and #2, where a number of small blocks have been identified.
- o Since at least some faults dip 55° to 60° , a monitoring well may be screened in a different block than that indicated by position of the well head; and

- o Drilling of a monitoring well may alter the original ground-water condition and create pathways for ground-water movement between blocks. This may be the case with MW-1, where the screened interval created a pathway for water movement (see cross-section).

3.0 CHARACTER OF PERMEABILITY OF WATER-BEARING ZONES

The character of the permeability of the water-bearing zones is a very important aspect of site hydrogeology, and is directly related to the applicability of a hypothetical plume migration model used by the applicant, and to the chances of early detection of contamination.

The hydrogeologic reports (App. 7 & 8) give no evaluation as to whether the permeability of site formations is of an intergranular, fracture, or mixed type.

Description of borehole samples within the water-bearing zones may be regarded as one possible source of information on the character of permeability. The presence of some fine to medium sand intercalations is indicated only in one case (MW-2). Water bearing zones occur in a sandy silt (piezometers C-1, C-4 and C-5), sandy clayey silt (MW-7), or sandy silty clay (MW-1, MW-4, C-1, C-4, C-5). So, except for MW-2, a water-bearing zone is associated with with fine-grained materials, an indication of a low intergranular type of permeability.

The presence of both joints and horizontal parting within the water-bearing section was noted only in MW-4. Horizontal parting was detected in MW-3 and G-5. Lost circulation of drilling fluid occurred in MW-1 and MW-6.

The results of the permeability testing are even more informative about the nature of permeability of the site rocks. Lab tests on remolded material produced values of 1.5×10^{-8} to 2.6×10^{-7} cm/s; field tests within the unsaturated zone in boreholes C-8 and C-9 yielded even smaller values (10^{-9}). These low permeability values are consistent with the gradation of most of the site materials; the values are characteristic of typical intergranular permeability of site formations, and constitute the lowest boundary of in-situ permeability.

Permeability test results for monitoring wells (involving about 30 feet of screened section in each well) gave much higher but variable values, ranging from 1×10^{-6} (MW-8) to 2.4×10^{-4} (MW-4). Except for MW-2, where the presence of sand can explain the relatively high permeability, the values ranging up to 2 to 3 orders of magnitude higher than permeability values for the matrix, intergranular permeability, and remarkable permeability variation between the wells, can only be explained by the presence of fractures, joints, or partings.

In jointed (fractured) rocks, permeability values depend on fracture aperture and spacing within the screened zone. Note, again, that vertical wells tend to greatly underrepresent the true spacing of steep fractures, or miss them entirely. This would explain variation in k values between wells. The evidenced sub-artesian conditions may only be apparent and indicative of encountering a fracture or fracture system (MW-8, C-16, C-4).

Lost circulation in sections of MW-1 and MW-6 is undoubtedly related to fracture zones, and may indicate even higher permeabilities than 10^{-4} cm/s. (The permeability test result in MW-1 appears suspect in the light of the reported fluid loss).

Relatively high values of fracture controlled permeability imply a potential for relatively fast ground-water movement. On the other hand, a long (though variable) residence time of ground water, as indicated by the isotope analysis, implies a very slow ground-water movement and hydraulic isolation of fault blocks. To satisfy both of these apparently contradictory implications, a very flat hydraulic gradient within a block would be required.

As the isotope analyses results play a crucial role in our perception of ground-water movement at the site, one can wonder what residence time would be assigned by the radiocarbon dating method for recent meteoric water moving through a fracture and partly mixing with pore water of Juana Diaz along its path of movement. The residence time would probably be within the thousands of years range, though water may be fairly recent.

Exploring further the concept of water moving through fractures and mixing with pore water, one would expect some inverse correlation between the concentration of chemical constituents and the "age" of water, with the concentration or age being somehow related to fracture flow velocity and/or the travel distance from a source of recharge to a well. Though ground-water chemistry data for the Ponce site are sketchy and surprisingly capricious, as revealed by Interim Status Monitoring (Tables 1 and 2 in Section E), some correlation emerges. Below are the data taken from Table 1 and p. 25 of Mayo's report (App. 8).

WELL	"AGE" (Years)	Cl ⁻ (mg/l)	SO ⁻² (mg/l)	COMMENTS
1	NA	750	310	Only one chemical analysis available
2	NA Recent?	1620-1940	480-1760	
3	6700	3620-4030	1880-2060	
4	10,200	3200-3760	841-1560	
6	1700	1690	680	Only one analysis
7	6500	892-1590	885-970	
8	3800	1100	450	Only one analysis

Ground water in deeper wells MW-1, MW-6, and MW-8 appears to belong to a more active flow system than the remaining wells. The fracture-controlled permeability concept offers a better explanation of large variations in the "age" and water chemistry. Large variations in concentrations of constituents during the monitoring period are contradictory to the concepts of stagnant ground water (or sampling and chemical analyses are suspect).

If the fracture type of permeability is dominant at the site, as it appears to be (except for sections screened in MW-2), then:

- o The ground-water flow direction may bear little relation to an apparent potentiometric surface;
- o Application of hypothetical models of plume migration, valid for intergranular permeability media, is questionable. The migration rate along fractures may be much faster than predicted by the model;
- o Unless a thorough analysis of jointing/fracturing, plus some type of tracer-test are conducted, the direction of potential contaminant migration cannot be determined reliably; and
- o There is a rather slim chance of detecting contaminants within the compliance point at several wells located near the waste management area.

4.0 "THE UPPERMOST AQUIFER" AND FLOW SYSTEMS AT THE SITE

The number of water-bearing zones (aquifers) and identification of the uppermost aquifer are prime aspects for ground-water monitoring. Unfortunately, these aspects are poorly explored and defined for the Ponce site.

In an attempt to evaluate the site hydrogeology, three hydrogeological sections and a graph of water level elevation in the monitoring wells and piezometers have been drawn (see attachments).

Water level data were only available for the period February to September, 1983 (App. 7), plus a single set of readings from March 1984. Continuity of readings between September 1983 and March 1984 would give a better understanding of water-level fluctuations and possible effects of precipitation on water levels. This effect appears to exist for piezometers C-1 and C-5, and possibly for C-6 and C-3, judging from water-level readings taken in March, May and September 1983. The fluctuation of water levels in relation to precipitation has not been addressed by the applicant, apparently on the

assumption that there is no relation between precipitation and "stagnant" ground water.

Abnormal behavior of the graph for MW-1 is very distinct and indicative of more than one water-bearing zone in the well vicinity. Drilling and screening of MW-1 partly in a more pervious fracture zone (fluid loss) appears to have resulted in drainage of water from the upper zone down through the fracture zone which was detected also in MW-6 (see Section A-A').

The water level in MW-6 is the lowest water level encountered south of the major site fault and is comparable with the water level in C-15 on the northern side of the fault. These levels are possibly at the same elevation as the water level in the Aqua Quebrada alluvium. The major fault trace passes under the alluvium some 1/2 mile west of the site (see regional map -- it is even likely that a splay of this fault influenced a section of the stream course). Therefore, the alluvium appears to be in hydraulic contact with the major fault (a recharge zone?).

Age dating and chemistry data for MW-6 indicate a more active flow system passing through the well than in some of the shallow wells. Thus, the ground-water chemistry and isotope data seem to indicate that the major fault zone (represented by more than one fault) is relatively pervious and acts as a drain and/or recharge source, and possibly discharging water to the alluvium southeast of the site. This interpretation resembles an earlier (April 1983) interpretation given by the applicant's consultants.

Unfortunately, the water-level data presented in the submission are limited to the site boundaries. Data on water-level elevations and the depth of three off-site wells located 0.5 miles East of the site might be helpful to better understand the complex site hydrogeology through a broader outlook.

In addition to the deeper and more active ground-water system, shallow and less active ground-water bearing zones occur at the site. Their character, vertical extent and relationship to the deeper system are still unclear and have yet to be defined.

Two different shallow water horizons were encountered in MW-2, where well screening connected the two zones. Chemical analyses obtained for the Interim Status Monitoring (Table 1 of Section E) indicate a rather fast and systematic "freshening" of water in the well with time. This may be attributed to mixing of two waters with originally different chemical characteristics.

A question arises as to the character of the zone which originally separated the two water horizons. A distinct gamma log intensity peak is observed at the separation level, indicating higher clay content and suggesting a stratigraphic character of the separation. On the other hand, a stratigraphic reversal (orange/green/orange/green/shale order) noted in the MW-2 borehole log and in a description (p. E-67), may be interpreted as a fault intersecting the well and marked by gamma peak intensity, possibly a clay gouge.

An association of shallow-water levels with the top of green shale and peaks of gamma intensity is a striking feature on the attached cross-sections. This may suggest some degree of stratigraphic control of ground-water occurrence at shallow depths; however, this hypothesis requires further understanding and refinement.

This association has an important implication for drilling of ground-water monitoring wells. The shallow water-bearing zones (whether of perched, isolated character or not) constitute "the uppermost aquifer" at the site in the regulatory sense.

When the top of the green shale is reached while drilling a monitoring well, drilling should progress with special care, possibly with frequent stops to determine the presence of a ground-water zone. It is likely (see sections) that either MW-6 missed the water zone, or water from the zone had been drained by MW-1. The same might have occurred in MW-8. (In order to prevent further communication between two water-bearing horizons, well MW-1 should be grouted.)

Judging from the proposed depths for new monitoring wells, the new wells are designed to monitor the deeper aquifer. Thus, the proposed monitoring system does not take into account the possible presence of a shallow water horizon (the uppermost aquifer).

5.0 CONCLUSIONS

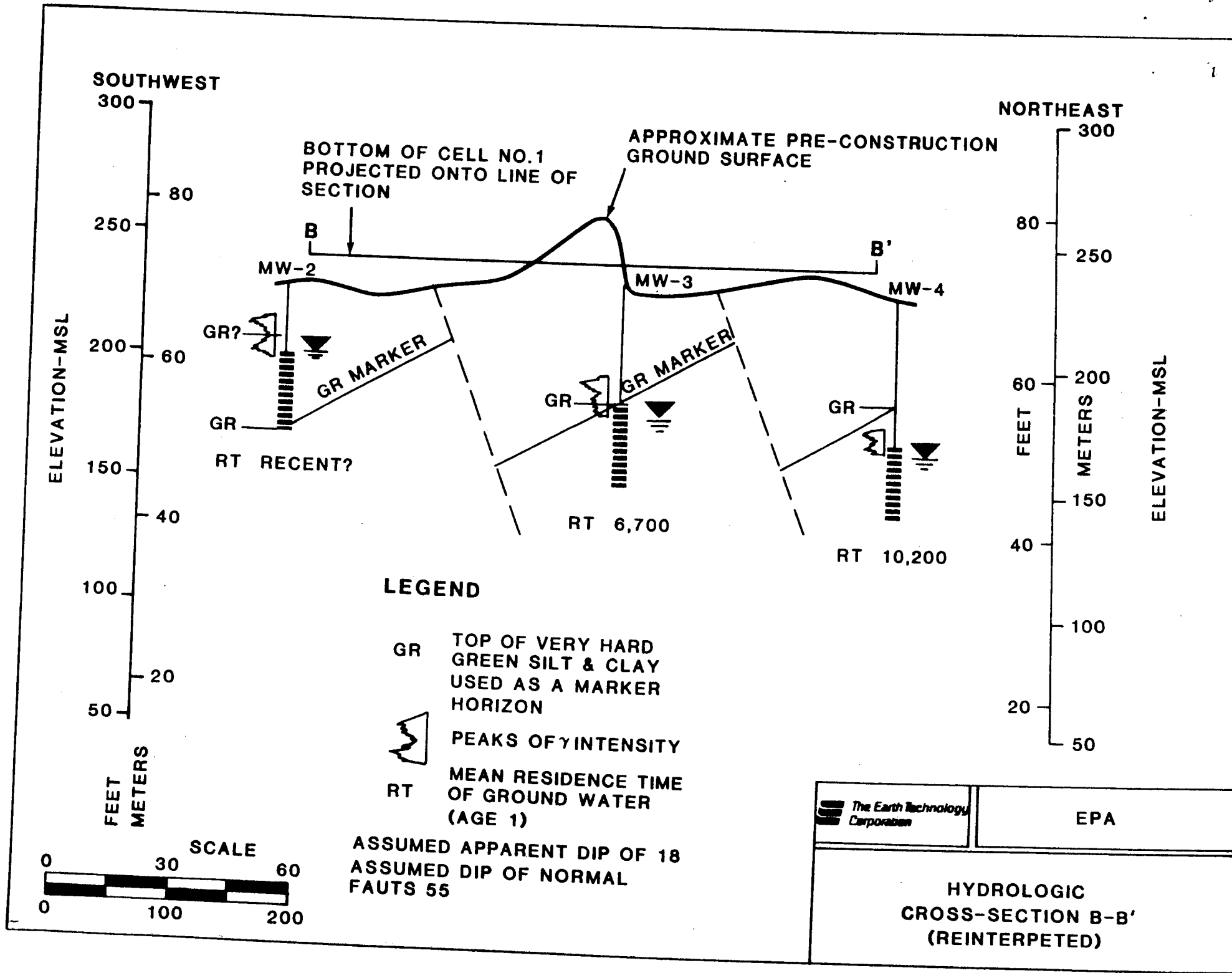
Based upon the geologic, hydrogeologic and geotechnical information compiled for the Ponce Center for Environmental Control, The Earth Technology Corporation has drawn the following conclusions:

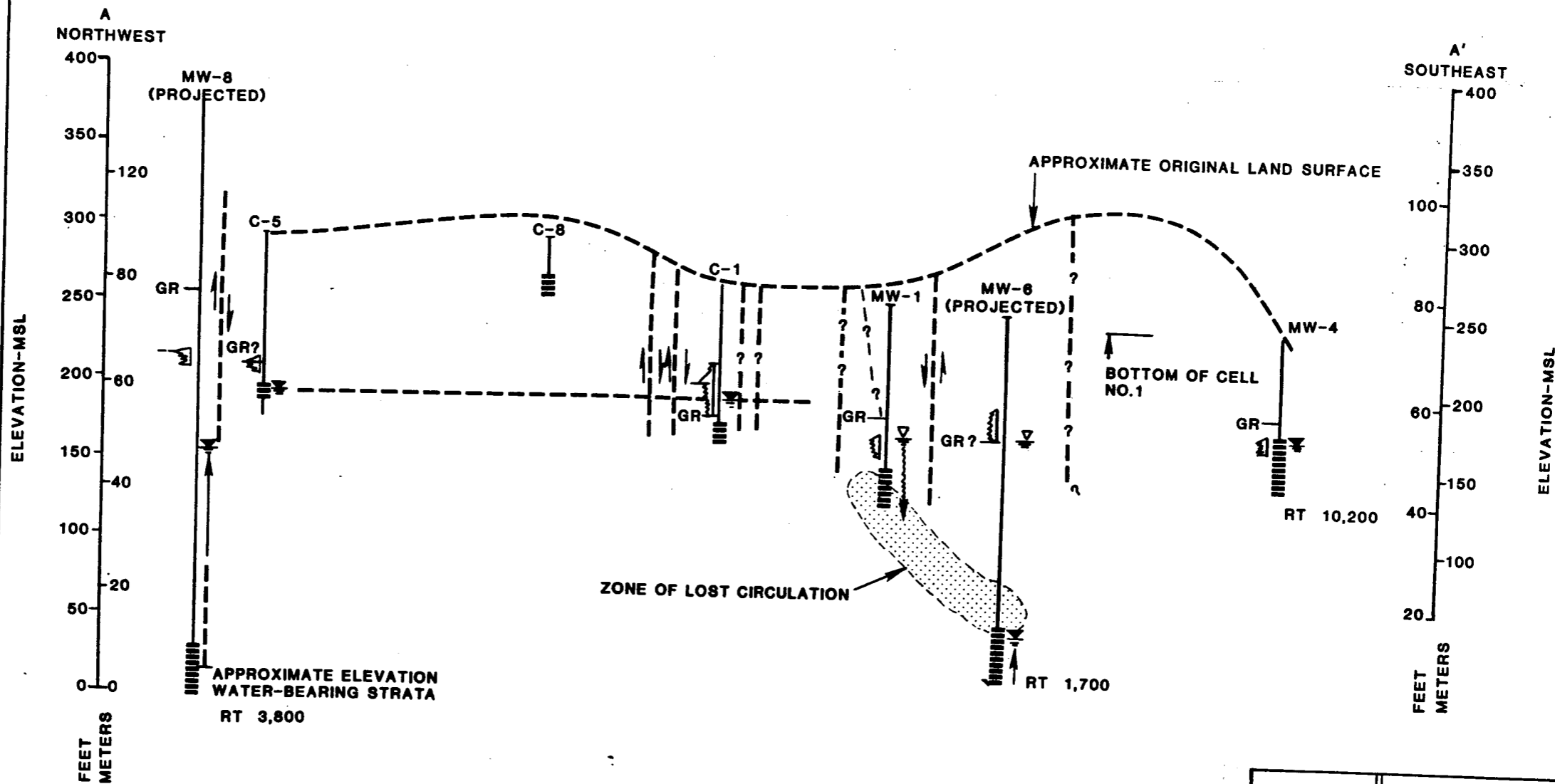
- o Due to the complexity of the Ponce site, the site hydrogeology is still inadequately defined, in spite of extensive exploration efforts. Both the applicant's and the reviewer's interpretations of ground-water occurrence and movement at the site are overly speculative.
- o The presence of many faults is the main reason for the site complexity. Four major fault trends have been identified. The number of tectonic blocks at the site appears to exceed the number of existing and proposed monitoring wells. A particularly complex block pattern is in the northern parts of Cells #1 and #2.
- o Identification of all major faults and fault blocks is a prerequisite for the characterization of the site hydrogeology and for establishment of an adequate monitoring system.
- o As evidenced by radiocarbon dating, the ground water is of meteoric origin.
- o More than one ground-water bearing zone and flow system are present at the site. The exact number, character, vertical and lateral extent, and relationship between the systems are still unknown and are subject to speculations. A deeper flow system appears to be more active than the shallow system(s).

- o Fracture permeability seems to be the dominant type of permeability, at least for the deeper aquifer. Therefore, the application of hypothetical models of plume migration, applicable to homogenous media with intergranular permeability, is questionable.
- o Boring logs, gamma logs and water-level data indicate that ground-water occurrence at shallow depths may, at least locally, be controlled by stratigraphy, in particular the green shale stratum.
- o The isotope analyses suggest a slow flushing of the fault controlled ground-water system; however, the widely varying residence times obtained in addition to drilling, water-level and chemistry data indicate that privileged, potential conduits for faster ground-water flow, exist at the site.
- o The proposed ground-water monitoring system represents a reasonable approach to monitoring; however, regulatory and technical concerns cast doubt as to the effectiveness of the system to "immediately" detect ground-water contamination.

FIGURES

Adapted from work completed by Law Engineering Testing, Co.





FIGURES

Adapted from work completed by Law Engineering Testing, Co.

